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Effect of Visual Range on Driving Speed on Low-grade Highway

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Abstract

Visual range from road alignments plays an important role in traffic safety since it is a key factor for drivers to adopt an appropriate speed. It is especially true to low-grade highways where speeds tend to reach a high value when sections have a relatively good linearity. High speeds on low-grade highway are considered a main contributor to traffic accidents. This paper studied the relationship of maximum visual range and driving speed on low-grade highways to put forward a suggested visual range for safe driving. Four typically mountainous highway models with the same driving environment but different visual ranges were constructed to analyze the effect of visual range on driving speed. A driving simulator with eight degrees of freedom was used to carry out the experiments. Data of driving speed, acceleration and deceleration were collected to study the speed and acceleration trends. The conclusion drawn is that the appropriate value of maximum visual range on low-grade highways is recommended to be 80m to ensure safety driving.

Keywords: Visual Range; Driving Speed; Low-grade Highway; Driving Simulator

1. Introduction

During the past three years, 44.8 percent of traffic accidents occurred on low-grade highways in China, around 40 percent of which were due to speeding (Jun and Zhao, 2011), imposing a serious threat to the safety of low-grade highways. Normally, drivers keep a low speed on most sections of low-grade highways except for those sections with good visual range where it is easy to lead drivers to raise speed to a high value. For example, on long tangent section or horizontal curve with large radius, drivers tend to drive at a speed much higher than limit speed. The situation becomes much worse when a bad-vision alignment (e.g. a sharp curve) follows the good vision sections. Moreover, it usually results in significant speed difference between adjacent sections, which

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poses a typical hazard on highways. Accordingly, the exploration of appropriate visual range to avoid over-speed on low-grade highway is of great significance.

Visual range is the visual scope that drivers can observe when driving on road. It allows drivers to predict what proper operation can be adopted when they enter it. Take a typical tangent section as an example. Visual range is not just the straight line between the driver and the farthest visual point but includes the length of the tangent and the observed adjacent curves. In the past decades, many researches focus simply on the relation between the driving speed and the tangent or the horizontal curve, and fail to take visual range into account. Actually, visual range has a noticeable influence on the drivers' behavior and different visual ranges of highways result in different driving speeds. If a proper visual range is adopted at the design stage of road alignment, the significant speed discrepancy will be mitigated or even eliminated. In this sense, an appropriate visual range is beneficial to reduce traffic accidents especially on low-grade highways.

2. Literature Review

Some researchers studied the influence of factors on driving speed on two-lane rural highway. Polus, Livnehect and Craus (1984) explored a number of factors which affected the operating speed on two-lane rural highway, and found that traffic volume and road alignment were the two main factors. Gibreel et al. (1999) presented a comprehensive study of the effect of road alignment design and confirmed that geometric design consistency had a noticeable effect on the changes of operating speeds. Misaghi and Hassan(2005) conducted experiments on two-lane rural highway to research the relationship of geometric features and the operating speed consistency, discovering that driver's perception of the road rather than the designer's was the main factor on speed decision. A good sight could offer drivers enough time for perception, reaction and operation, to adopt appropriate measures to control the driving speed. Gattis and Duncan (1995) proposed that the required preview time on two-lane rural highway shouldn't be less than 1.3s-1.7s in order to provide drivers enough time to response when there was an emergency. Lamm and Choueiri (1987) developed the speed prediction model for curves on two-lane highway, and recommended 94.7 km/h, which was obtained from the model with an infinite radius, as the operating speed on long tangent sections (>200m). And various operating speeds were proposed for long tangent sections. Krammes et al. (1995) recommended 97.4km/h, Hassan, Gibreel and Easa (2000) recommended 102.0km/h, and Misaghi and Hassan (2005) suggested 103.0km/h.

Some researchers have done research about effect of long tangent length on driving speed. Polus, Fitzpatrick and Fambro (2000) analyzed the speed data gathered from 162 tangent sections on two-lane rural highways, and then drew the conclusion that the vehicle speed on tangent section was primarily dependent on the tangent length and the radius of horizontal curve before and after the section. Chung et al. (2001) performed an experiment to verify the strong influence that the long tangent section had on driving behaviors. The outcome was that the intensity value of β brainwave decreased with a relatively high magnitude on tangent sections when driving time lasted for more than 60 minutes, and the maximum length of tangent section for road design was 4.2 kilometers. Kay Fitzpatrick et al. (2005) discussed the relationship between the operating speed on tangent sections and the road characters, and obtained the conclusion that if the tangent length between two adjacent sharp turns was far enough, the operating speed would remain unchanged after reaching a maximum value. HE and Sun (2010) focused on the variation of operating speeds on long tangent sections, and concluded that high driving speed usually resulted from drivers' tendency of speeding. María Castro et al. (2011) carried out experiments on 22 curves on two-lane rural highways in Colombia to describe the speed change from tangent section to curve, and developed operating-speed prediction models for both curves and tangent section. Zilioniene and Vorobjovas (2011) investigated the horizontal alignment of 30 regional roads, finding that sight distance, as one of the safety assessment indexes, directly affected the acceleration and deceleration performance of vehicles on long tangent section.

From what has been presented above, it can be seen that most studies put more emphasis on the relation between driving speed and tangent length and the influence of visual range on driving speed has not yet gotten enough attention. However, in real driving condition, the visual range usually plays a direct role in speed control, moreover driver's direct feeling correlates to the visual environment, so it is necessary to research the relationship between visual range and driving speed on low-grade highway.

In this research, four typically low-grade highway models with same mountainous driving environment but different visual ranges (20 m, 35m, 70m and 130m respectively) were constructed to explore the definite correlation between visual range and driving speed, and an appropriate value of maximum visual range on low-grade highway is recommended.

3. Data Collection

3.1. Driving simulator collection

The simulator has a dynamic system with eight degrees of freedom as shown in Fig. 1. The cockpit is in rigid structure and completely enclosed. The simulation vehicle is Renault Megane III, which is placed in the center of the cockpit. Five projecting apparatus are installed to form the simulation scenarios, the horizontal view angle of which is 250 degrees and vertical view angle is 40 degrees. The simulator, equipped with advanced technology, can provide the scenario of real driving environment consisting of the driver, vehicle, traffic flow and road facilities.

The software SCANeR StudioTM embedded in the simulator is programmed to control the operating system, establish the three-dimensional models, and collect experimental data. The data includes the position of the vehicle, travel distance, driving speed and acceleration and deceleration of the vehicle, etc. They are recorded every 0.1 second by the software SCANeR StudioTM. Because of the real simulation scenario and the accuracy of the software, the data collected is accurate and in a large quantity.

Fig. 1. Driving simulator

3.2. Experiment description

Based on the road alignment and driving environment of a real low-grade highway in Sichuan Province, a mountainous region in China, four simulation roads with different visual ranges (20m, 35m, 70m and 130m respectively) were constructed. The simulated route included one tangent section and its adjacent curves whose radius were both 16m. The purpose of the design is to ensure the entering speed to tangent section being consistent with the design speed (20km/h) and exclude other irrelevant factors. The length of the visual range is a little longer than that of the tangent section. The alignment elements of the contrast roads are displayed in Table 1. The alignment elements are shown in Fig. 2.

Table 1 Alignment elements of four experimental roads

Preceding Curve Radius (m)	Preceding Curve Length (m)	Visual Range (m)	Tangent Length (m)	Succeeding Curve Radius(m)	Succeeding Curve Length (m)
16	21.56	20	15	16	17.80
16	21.56	35	30	16	17.80
16	21.56	70	65	16	17.80
16	21.56	130	125	16	17.80

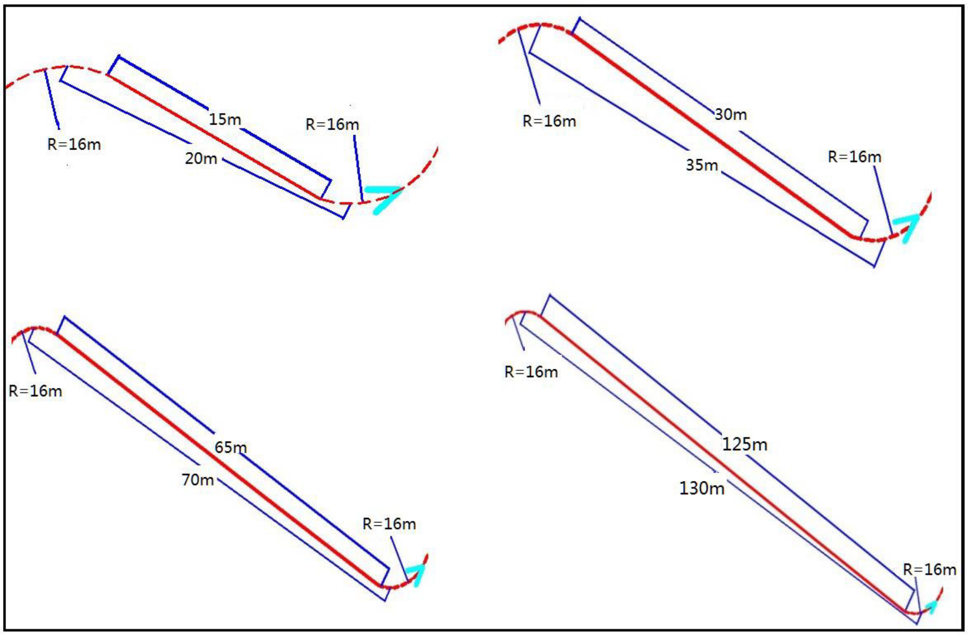


Fig. 2. Alignments of four contrast roads

Thirty drivers are selected as participants, including 16 men and 14 women. Among them, 21 drivers are 23-45 years old and the other 9 are above 45 years old. The average driving years of these drivers is 7.7 years, with the range of 2-12 years. 48% of them have violation record of over-speed.

In order to diminish the probable discrepancy of the driving performance under real and simulating conditions, all the drivers were trained to adapt to the simulation driving environment before the experiment. The adaption driving took 0.5 to 1.0 hours according to different driving habits of drivers. After they were familiar with the simulating circumstance, the experiment began. In the experiment process, every driver was asked to drive respectively on the four experimental roads for two times. They drove alternately and on different days in order to avoid driving fatigue. The driving scenes are shown in Fig. 3.

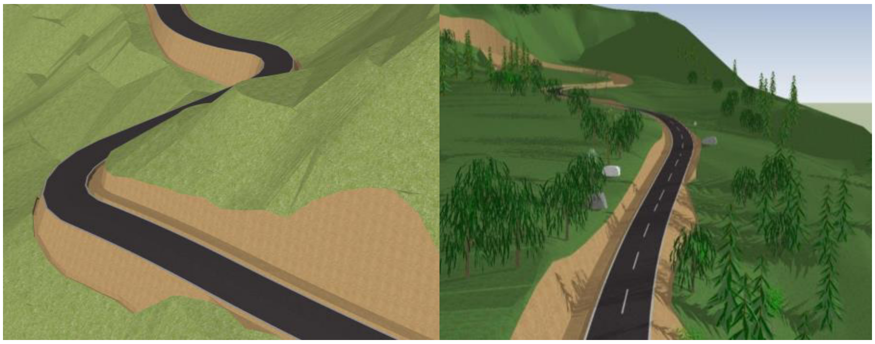


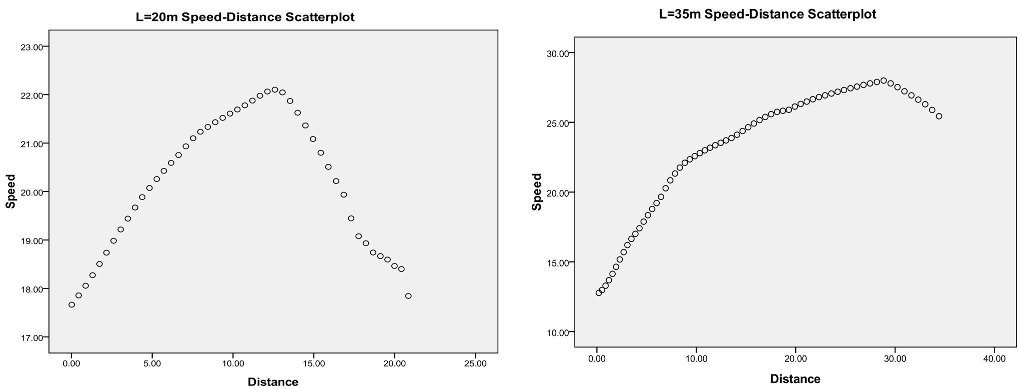
Fig. 3. Simulation Scenes

4. Results Analysis

4.1. Speed trend analysis

Because of the small radius of the preceding curve, most drivers drove below 20km/h (the design speed) before entering tangent section except in the last model. Once entered, drivers tended to raise speed due to better vision. When the vision was restrained by succeeding curve with small radius (R=16m), speeds went down correspondingly.

The speed variations of the thirty drivers at different visual ranges are almost the same in spite of their different personalities. Data of a typical driver was taken as an example to plot how the driving speed changes along with travel distance. Scatter diagrams were shown in Fig. 4.



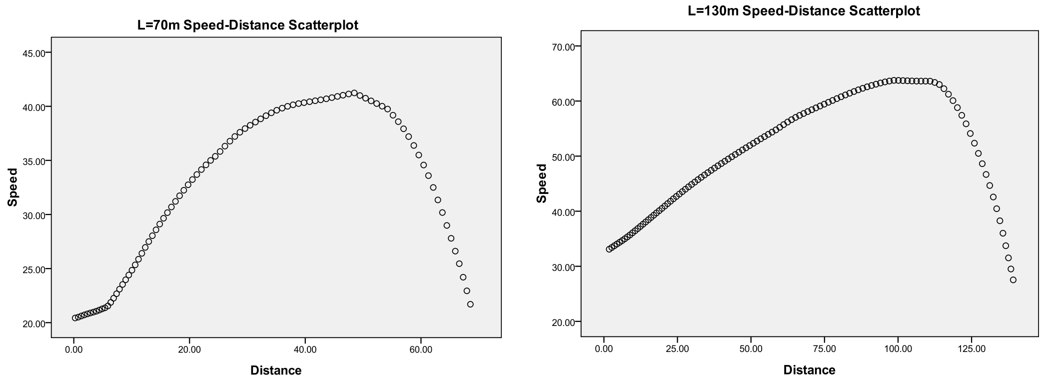


Fig. 4. Speed trends along with travel distance

The speed trends under four different visual ranges were analyzed in detail. When the visual range was 20m, driving speed didn't rise much before the car left the experimental section. The average entering speed of all the thirty drivers was 18km/h, the average maximum driving speed was 22km/h, and the corresponding driving distance when vehicles reached the speed was around 12 m. When the visual range was 35m, the average maximum speed was approximate 28km/h after running for about 28m. Then it decreased immediately because the bad vision on the succeeding curve. It decreased rapidly to 20km/h, making the exiting speed more or less the same with the entering speed. No drivers were seen to keep a steady driving on the road. When the visual range expanded to 70m, the average maximum speed mounted to 41km/h, and the corresponding travel distance was 53m. Constant driving seemed to appear. When the visual range was added to 130m, the average maximum speed was 62km/h and there appeared a steady driving in all of the drivers' performance.

With comparison of the four diagrams, it can be found that when visual range is 20m, 35m or 70m, no driver drove at an exceedingly high speed. Another phenomenon is that the maximum speeds under different visual ranges are different. The further the visual range is, the higher the maximum speed increases to. The line graph is drawn to show the linear correlation. See in Fig. 5. X-axis represents the visual range. Y-axis represents the maximum speed.

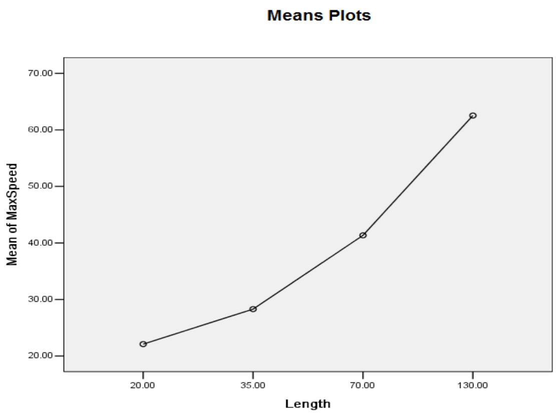


Fig. 5. Graph of visual range and maximum speed

When the visual range extends to 130m, the maximum speed mounted to 62km/h, nearly 38km/h higher than entering speed. The significant speed difference is definitely unfavorable to road safety. Therefore, it is necessary to limit visual range to prevent speeding. From Figure 5, it can be seen when visual range is around 80m, maximum speed achieved to about 45km/h. The speed difference is just over 20km/h which is considered the largest permitted difference in safety evaluation. In this sense, in order to ensure traffic safety, the appropriate visual range is recommended 80m.

4.2. Acceleration trend analysis

The acceleration and deceleration trends of the thirty drivers under four different visual ranges were also analyzed. The trend was in consistent with the speed variation. The data of the same driver was used to draw the trends of acceleration and deceleration. The diagrams are shown in Fig. 6.

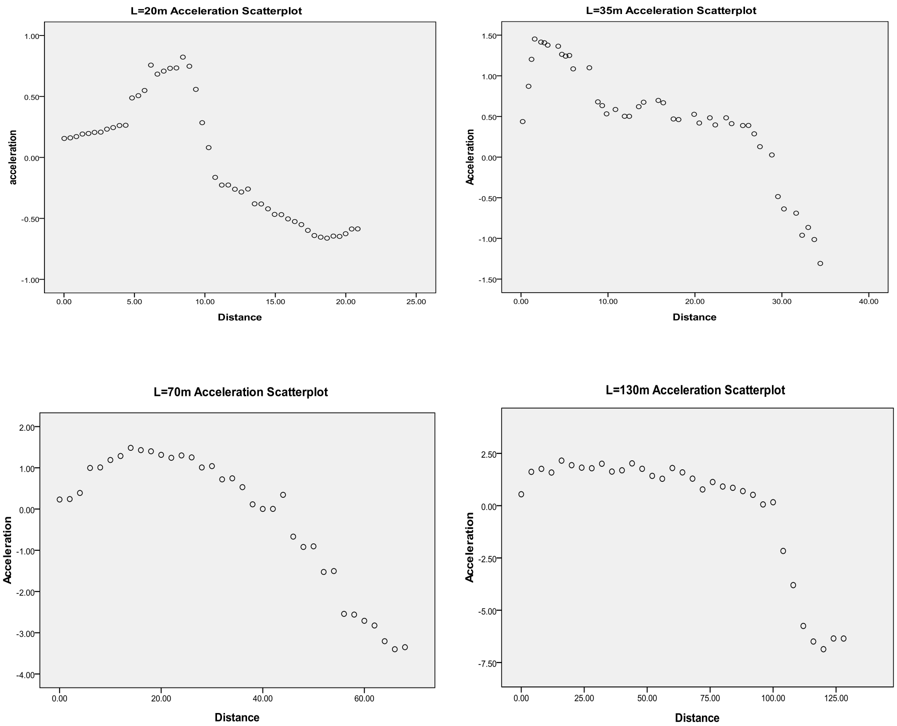


Fig. 6. Variation trends of acceleration and deceleration

The comparison of the diagrams shows that the values of the acceleration and deceleration distribute either just over or under 0m/s2 when the visual ranges are 20m, 35m and 70m respectively. It means that driving speed does not increase dramatically. When the visual range is 130m, it is obviously seen that acceleration is relatively high and levels off for some distance, which reflects the continuing speeding behavior of the driver.

4.3. Analysis of variance

ANOVA was used to do the mathematical analysis of the correlation between visual range and maximum driving speed. Based on the four designed visual ranges, the collected data of speed were assembled into four different groups, representing four different levels. Every group includes thirty samples which refer to the thirty maximum driving speeds under this visual range. The maximum speed is regarded as the dependent variable. The visual range is regarded as the independent variable. To test the assumption that the population of each group is of the equal variance, the Homogeneity of variance test is used. The result of the test is shown in Table 2.

Table 2 Test of homogeneity of variances

Speed

Levene Statistic	df1	df2	sig.
4.218	3	116	.007

In Table 2, The Sig. value is 0.007, greater than the significant level 0.05, so the hypothesis of homogeneity of variances can be accepted. It is believed the population variances are homogenous. The ANVOA method can be used to test whether the maximum speed is significantly affected visual range. The ANOVA result is displayed in Table 3.

Table 3 ANOVA

Speed

			Sum of Squares	df	Mean Square	F	Sig.
Between Groups	(Combined)		28805.794	3	9601.931	1784.777	.000
	Linear Term	Contrast	28764.716	1	28764.716	5436.695	.000
		Deviation	41.077	2	20.539	3.818	.025
Within Groups			624.069	116	5.380		
Total			29429.863	119			

In Table 3, the F value is 1784.777 and the Sig value is 0.000, indicating that the "Between Groups" variation can explain a relatively large portion of the variation in maximum speeds. The visual range indeed exerts a significant impact on maximum speed. As such, it makes sense to go further and compare the difference in maximum speeds across different visual range levels.

Although it is determined that differences exist among the four groups of maximum speeds, it cannot allege that they are completely different from one another. Thus, it is necessary to know which groups differ. Table 4 reports the comparisons of means between different groups.

In the "Sig." column, the "Sig" values are all 0.000, meaning that there exist significant differences between every two groups of maximum speeds. The column "Difference (I-J)" shows the estimated differences between maximum speeds.

The ANOVA method confirms that the influence of the visual range is so significant that every group of the maximum speed is totally different from the rest ones.

Table 4 Multiple Comparisons

Dependent Variable: Speed

	(I) distance	(J) distance	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	20.00	35.00	-6.54300*	.59888	.000	-7.7292	-5.3568
		70.00	-19.76533*	.59888	.000	-20.9515	-18.5792
		130.00	-40.54833*	.59888	.000	-41.7345	-39.3622
	35.00	20.00	6.54300*	.59888	.000	5.3568	7.7292
		70.00	-13.22233*	.59888	.000	-14.4085	-12.0362
		130.00	-34.00533*	.59888	.000	-35.1915	-32.8192
	70.00	20.00	19.76533*	.59888	.000	18.5792	20.9515
		35.00	13.22233*	.59888	.000	12.0362	14.4085
		130.00	-20.78300*	.59888	.000	-21.9692	-19.5968
	130.00	20.00	40.54833*	.59888	.000	39.3622	41.7345
		35.00	34.00533*	.59888	.000	32.8192	35.1915
		70.00	20.78300*	.59888	.000	19.5968	21.9692
Bonferroni	20.00	35.00	-6.54300*	.59888	.000	-8.1506	-4.9354
		70.00	-19.76533*	.59888	.000	-21.3729	-18.1578
		130.00	-40.54833*	.59888	.000	-42.1559	-38.9408
	35.00	20.00	6.54300*	.59888	.000	4.9354	8.1506
		70.00	-13.22233*	.59888	.000	-14.8299	-11.6148
		130.00	-34.00533*	.59888	.000	-35.6129	-32.3978
	70.00	20.00	19.76533*	.59888	.000	18.1578	21.3729
		35.00	13.22233*	.59888	.000	11.6148	14.8299
		130.00	-20.78300*	.59888	.000	-22.3906	-19.1754
	130.00	20.00	40.54833*	.59888	.000	38.9408	42.1559
		35.00	34.00533*	.59888	.000	32.3978	35.6129
		70.00	20.78300*	.59888	.000	19.1754	22.3906

*. The mean difference is significant at the .05 level.

5. Conclusion

From the analyses above, the conclusion can be drawn that there is a remarkable influence of the visual range on driving speed. The relationship is positively correlated. The longer the visual range is, the higher the speed reaches. If the visual range is further than 80m, the speed will increase much higher resulting in significant speed difference (>20km/h) which poses threat to traffic safety. Hence, the appropriate value of maximum visual range is suggested 80m, which is effective to limit maximum speed within a relatively reasonable range.

This conclusion offers practical guideline for road alignment designers and useful information for safety evaluation of low-grade highways. It is normally believed that the better the visual range is, the safer the driving environment becomes. However, in this paper, it turns out this is not always the case. If the visual range is too large, it easily leads to a big speed difference between the adjacent parts. So the length of visual range should correspond with the design standard of the whole road. Some work needs to be done to further explore the issue:

- A much more appropriate visual range can be determined when taking into account other relevant factors, such as slope gradient, vertical alignment, width of the road, etc.
- More participants should be recruited to do the research experiment to represent general driving behavior.
- Data should also be collected from experiments on real roads to verify the conclusion obtained on the basis of simulation experiment in this paper.

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